Multi-Agent Systems

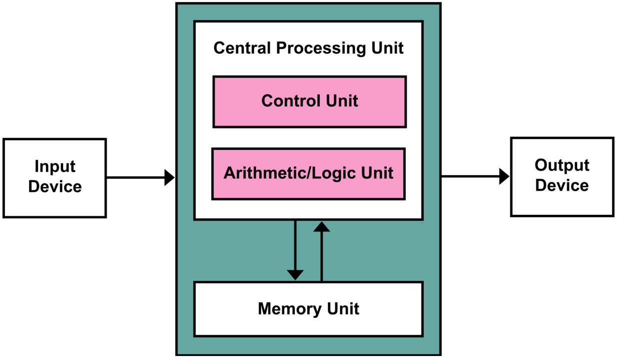
Albert-Ludwigs-Universität Freiburg

Bernhard Nebel, Felix Lindner, and Thorsten Engesser

Summer Term 2017

Course outline

Von-Neumann Architecture



Agent Architectures

Definition: Agent Architecture

An agent architecture proposes a particular methodology for building an autonomous agent: Set of component modules and interaction of these modules determines how perception and current state of the agent determine its next action and next internal state.

Agents: Standard View

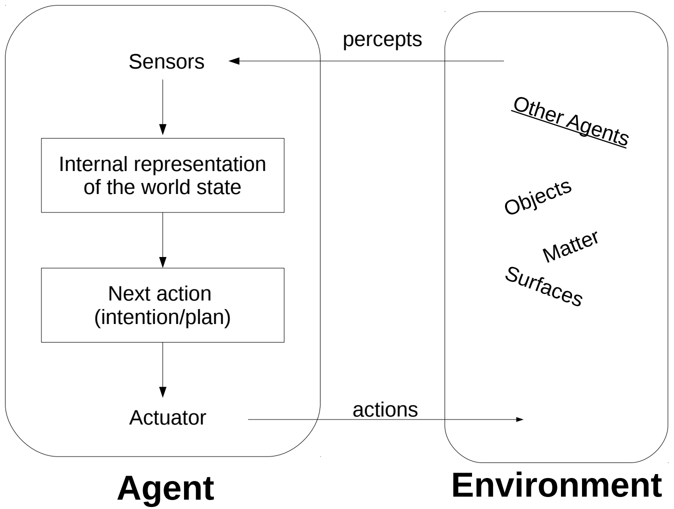


Table-Driven Agent

```
function TABLE-DRIVEN-AGENT($percept$)
    global $table, percepts$
    $percepts \leftarrow$ APPEND($percepts, percept$)
    $action \leftarrow$ LOOKUP($percepts, table$)
    return $action$
end function
```

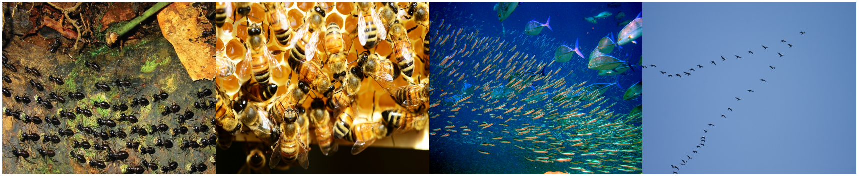
- Epistemic state is the list of percepts so far perceived.
- Practical reasoning based on look-up table.

Simple Reflex Agent

```
function SIMPLE-REFLEX-AGENT(percept)
    global rules
    state ← INTERPRET-INPUT(percept)
    rule ← RULE-MATCH(state, rules)
    action ← RULE-ACTION(rule)
    return action
end function
```

- Epistemic state is just the current percept.
- Practical reasoning based on condition-action rules.

Swarms of Simple Reflex Agents



- Swarm formation control: How to design programs that result into a particular swarm formation when executed on each simple reflex agent. Video: EPFL Formation

Formation Control: General Setting

- Problem
  - Form an approximation of a simple geometric object (shape)
  - Problem not yet solved in general!
  - Algorithms exists that make simplifying assumptions about the agents' capabilities and the shape.
- Assumptions shared by the algorithms proposed by Sugihara & Suzuki (1996)
  - Each robot can see all the other robots
  - Shapes are connected
  - But ...
  - Total number of robots unknown
  - No common frame of reference (i.e., one cannot program the robots "to meet at point (X, Y)" or "to move north")
  - robots cannot communicate with each other
  - Local decision making

Formation Control: CIRCLE

- Problem: Move a group of robots such that they will eventually approximate a circle of a given diameter D.
- Algorithm [Sugihara & Suzuki, 1996]: The robot R continuously monitors the position of a farthest robot R_{far} and a nearest robot R_{near}, and the distance d between R (itself) and R_{far}.
  1. If $d > D$, then R moves towards R_{far}
  2. If $d < D - \delta$, then R moves away from R_{far}
  3. If $D - \delta \leq d \leq D$, then R moves away from R_{near}

Formation Control: CIRCLE

- Problem: Move a group of robots such that they will eventually approximate a circle of a given diameter D.
- Algorithm [Sugihara & Suzuki, 1996]: The robot R continuously monitors the position of a farthest robot R_{far} and a nearest robot R_{near}, and the distance d between R (itself) and R_{far}.
  1. If $d > D$, then R moves towards R_{far}
  2. If $d < D - \delta$, then R moves away from R_{far}
  3. If $D - \delta \leq d \leq D$, then R moves away from R_{near}

Formation Control: POLYGON

- Problem: Move a group of N robots such that they will eventually approximate an $n \ll N$-sided polygon.

- Algorithm [Sugihara & Suzuki, 1996]:
  1. Run the CIRCLE algorithm until each robot R can recognize its immediate left neighbor $l(R)$ and right neighbor $r(R)$.
  2. Selection of n robots to be the vertices of the n-sided polygon.
  3. All robots R execute the CONTRACTION algorithm
     1. Continuously monitor the position of $l(R)$ and $r(R)$
     2. Move toward the midpoint of the segment $\overline{l(R)r(R)}$

Formation Control: POLYGON

- Problem: Move a group of N robots such that they will eventually approximate an $n \ll N$-sided polygon.

- Algorithm [Sugihara & Suzuki, 1996]:
    1. Run the CIRCLE algorithm until each robot R can recognize its immediate left neighbor $l(R)$ and right neighbor $r(R)$.
    2. Selection of n robots to be the vertices of the n-sided polygon.
    3. All robots R execute the CONTRACTION algorithm
        1. Continuously monitor the position of $l(R)$ and $r(R)$
        2. Move toward the midpoint of the segment $\overline{l(R)r(R)}$

Formation Control: FILLCIRCLE

- Problem: Move a group of robots such that they will eventually distribute nearly uniformly within a circle of diameter D.

- Algorithm [Sugihara & Suzuki, 1996]: The robot R continously monitors the position of a farthest robot R_{far} and a nearest robot R_{near}, and the distance d between R (itself) and R_{far}.
    1. If $d > D$, then R moves toward R_{far}.
    2. If $d \leq D$, then R moves away from R_{near}.

Formation Control: FILLCIRCLE

- Problem: Move a group of robots such that they will eventually distribute nearly uniformly within a circle of diameter D.

- Algorithm [Sugihara & Suzuki, 1996]: The robot R continously monitors the position of a farthest robot R_{far} and a nearest robot R_{near}, and the distance d between R (itself) and R_{far}.
  1. If $d > D$, then R moves toward R_{far}.
  2. If $d \leq D$, then R moves away from R_{near}.

Formation Control: FILLPOLYGON

- Problem: Move a group of N robots such that they will eventually distribute nearly uniformly within an $n \ll N$-sided convex polygon.

- Algorithm [Sugihara & Suzuki, 1996]: First n robots are picked as vertices of the polygon and moved to the desired position. All other robots R execute FILLPOLYGON:
  1. If, as seen from R, all other robots lie in a wedge whose apex angle is less than π, then R moves into the wedge along the bisector of the apex.
  2. Otherwise, R moves away from the nearest robot.

Formation Control: FILLPOLYGON

- Problem: Move a group of N robots such that they will eventually distribute nearly uniformly within an $n \ll N$-sided convex polygon.
- Algorithm [Sugihara & Suzuki, 1996]: First n robots are picked as vertices of the polygon and moved to the desired position. All other robots R execute FILLPOLYGON:
    1. If, as seen from R, all other robots lie in a wedge whose apex angle is less than π, then R moves into the wedge along the bisector of the apex.
    2. Otherwise, R moves away from the nearest robot.

Formation Control: LINE

- Problem: Move a group of robots such that they will eventually connect to points. (In fact, just a special case of FILLPOLYGON.)

- Algorithm [Sugihara & Suzuki, 1996]: First, two robots are picked as vertices of the line and moved to the desired position. All other robots *R* execure FILLPOLYGON.

Formation Control: LINE

- Problem: Move a group of robots such that they will eventually connect to points. (In fact, just a special case of FILLPOLYGON.)

- Algorithm [Sugihara & Suzuki, 1996]: First, two robots are picked as vertices of the line and moved to the desired position. All other robots *R* execure FILLPOLYGON.

When Memory Helps

- Simple reflex agent's do not make use of memory. This is a severe limitation:
  - Imagine you are at a crossing and you have to decide to either go left or right. You go left and find out it's a dead end. You return to the crossing. Again, you have the choice between going left and going right ...
  - Possible solutions:
    - Change the environment (pheromones, bread crumbs)
    - Put your previous actions and experiences into your memory

Reflex Agent With State

```
function REFLEX-AGENT-WITH-STATE($percept$)
    global $rules, state$
    $state \leftarrow$ UPDATE-STATE($state, percept$)
    $rule \leftarrow$ RULE-MATCH($state, rules$)
    $action \leftarrow$ RULE-ACTION($rule$)
    $state \leftarrow$ UPDATE-STATE($state, action$)
    return $action$
end function
```

- Epistemic state is updated over time (takes both state and percept into account and thus can also update currently unobserved aspects).
- Practical reasoning is based on rules applied in this state and leads to another state update.

Goal-Based Agent

```
function GOAL-BASED AGENT(percept)
    global state, actions, goals
    state ← UPDATE-STATE(state, percept)
    predictions ← PREDICT(state, actions)
    action ← BEST-ACTION(predictions, goals)
    state ← UPDATE-STATE(state, action)
    return action
end function
```

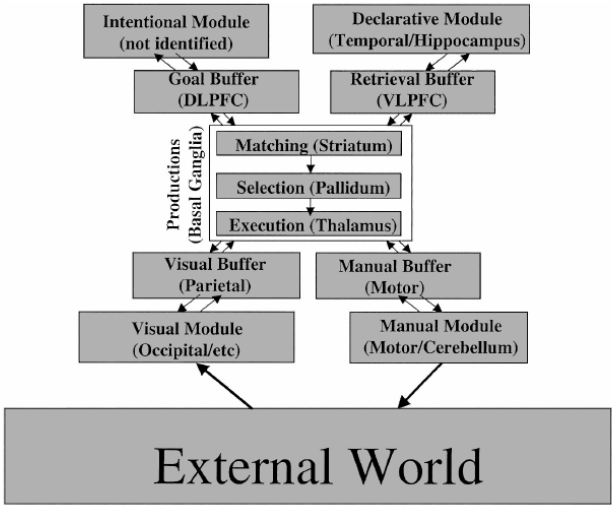
- Practical reasoning more flexible due to explicitly representing actions and goals instead of rules, i.e., “Will the world state be consistent with my goals if I execute action A?”

Utility-Based Agent

```
**function** UTILITY-BASED-AGENT(*percept*)
    global *state*, *actions*, *utilities*
    *state* ← UPDATE-STATE(*state*, *percept*)
    *predictions* ← PREDICT(*state*, *actions*)
    *action* ← BEST-ACTION(*predictions*, *utilities*)
    *state* ← UPDATE-STATE(*state*, *action*)
    **return** *action*
**end function**
```

- Practical reasoning more decisive due to the ability to take utilities into account, i.e., “Is action A the best action among the available actions?”

Cognitive Agent: ACT-R


Intentional Module (not identified)
Declarative Module (Temporal/Hippocampus)
Goal Buffer (DLPFC)
Retrieval Buffer (VLPFC)
Productions (Basal Ganglia)
Matching (Striatum)
Selection (Pallidum)
Execution (Thalamus)
Visual Buffer (Parietal)
Manual Buffer (Motor)
Visual Module (Occipital/etc)
Manual Module (Motor/Cerebellum)
External World

ACT-R: Activation and Learning

- Activation
  - Entries in the declarative memory are called chunks
  - Chunks have a degree of activation
  - Activation of chunks activates associated chunks
  - Chunks' activation descreases over time and fall below the retrieval threshold (forgetting)
- Utility Learning
  - The rules of an ACT-R agent are called productions
  - Production have utility: $U_i = P_i G - C_i$
  - Probability of success: $P = \mathit{success} / (\mathit{success} + \mathit{failures})$
  - Cost equation: $C = \sum_j \mathit{effort}_j / (\mathit{successes} + \mathit{failures})$
  - G: Some fixed importance of the current goal
  - Production choice: $\mathit{Prob}_i = e^{U_i/\mathit{noise}} / (\sum_j^n e^{U_j/\mathit{noise}})$

BDI Agent

```
**function** BDI-AGENT(*percept*)
    global *beliefs*, *desires*, *intentions*
    *beliefs* ← UPDATE-BELIEF(*beliefs*, *percept*)
    *desires* ← OPTIONS(*beliefs*, *intentions*)
    *intentions* ← FILTER(*beliefs*, *intentions*, *desires*)
    *action* ← MEANS-END-REASONING(*intentions*)
    *beliefs* ← UPDATE-BELIEF(*action*)
    **return** *action*
**end function**
```

- BDI agents start out with some beliefs and intentions.
- Intentions are goals the agent has actually chosen to bring about (can be adopted and dropped).
- Beliefs and intentions constrain what the agent desires.
- Together, B, D, and I determine the agent's future intentions.

Quiz

- Let us think back to the first session of this lecture and to the entities we identified as agents:
  - Humans
  - Animals
  - Plants
  - (Self-driving) cars
  - Light switches
- Which architecture would you pick to implement each of these agents?

Course outline

Literature I

- Stuart Russell and Peter Norvig, Artificial Intelligence: A Modern Approach, second edition, Prentice Hall, 2003.
- K. Sugihara, I. Suzuki, Distributed Algorithms for Formation of Geometric Patterns with Many Mobile Robots, Journal of Robotic Systems, Vol. 13, No. 3, pp. 127–139, 1996.